

MONITORING SYSTEM

The present invention relates to a system for monitoring conditions within a vessel a wall of which defines an enclosed space and a sensor array for mounting within such a vessel.

Process tomography systems have been designed which can obtain valuable information about process conditions within vessels. In many situations however it is undesirable or unacceptable to penetrate a process vessel with cables to enable communication with sensors located within that vessel. Typical situations in which such restrictions apply are stirred tank reactors, fluidised beds, separators, cyclones, hydraulic and pneumatic conveyors, crystallisers and the like. Particularly in the case of bioreactors where sterility is an essential requirement, or pharmaceutical manufacturing where high integrity containment is required to guarantee an uncontaminated workplace and product, it is highly undesirable to have cables penetrating the walls of process vessels.

Typical tomography systems require a symmetrically distributed set of transducers from which sample data produces a set of "projections" through the process. These are then "reconstructed" to form an estimate of the cross-section interrogated by the sensor array in terms of the parameters sensed by the transducers. A range of process information may then be estimated, for example volume fraction in a flowing mixture, solids concentration in stirred reactors, density distribution in a product and the like.

Typically transducers are arranged either singly or in pairs or in groups to measure a range of parameters. Examples are electrical capacitance measuring systems, electrical resistance measuring systems, electromagnetic inductance measuring systems, acoustic and ultrasound reflection and transmission measuring systems, X-ray transmission measuring systems, and nuclear magnetic resonance measuring systems. In some processes two or more types of transducers are used in order to gain sensitivity to a range of materials within the process. Such applications are typically described as multi-modal tomography applications.

When a set of distributed transducers is used it is desirable that each transducer comes into close contact with or proximity to the process at a particular

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geometric position. In a simple case each transducer may make such contact through a hole or opening formed at an appropriate location in a process vessel wall. Although such an approach is simple and direct and can readily be used for experimental purposes and may be viable in some practical circumstances, there are also many situations in which such penetration of a vessel wall is undesirable.

A further problem which can be encountered when seeking to fit tomographic sensors within a process vessel is that of appropriately positioning sensors on the inside of a process vessel wall, particularly in situations where it is inappropriate to make connections to the sensors directly through that wall. There are also applications in which the process vessel includes mechanical structures such as stirrers which prevent the surface mounting of bulky sensor assemblies on the process vessel wall. This makes it very difficult in many circumstances for tomography sensors to be retro-fitted to existing process vessels.

It is an object of the present invention to obviate or mitigate some or all of the problems outlined above.

The present invention provides a tomographic sensor array for mounting on a support within a vessel to enable conditions within the vessel remote from that support to be monitored, comprising a sheet carrying an array of sensors and conductors connecting the sensors to at least one output through which signals may be transmitted which are representative of conditions within the vessel.

The invention as defined in the preceding paragraph makes it possible to readily position sensors suitable for connection to a tomographic imaging system inside a process vessel without requiring significant clearance above the original process vessel wall surface, the relative positioning of different components of the sensor array being determined by the position of the components on the sheet.

The sheet may be a laminar construction with the conductors defined by conductive tracks or element deposited on an insulating substrate. Alternatively, the conductors may be defined by conductive elements supported within the sheet.

The conductive tracks or element may be covered with an electrically insulating layer, and the sensors may also be covered with the electrically insulating layer.

The sheet may be flexible.

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The sheet may comprise a series of sections which are interconnected such that at least some of the conductive tracks extend across the interconnections between the sections

According to the present invention, there is also provided a system for monitoring conditions within a vessel a wall of which defines an enclosed space, comprising a plurality of sensors which in use are distributed within the vessel, a first monitoring unit located within the vessel and connected to each of the sensors, and a second monitoring unit located outside the vessel, the first monitoring unit comprising means for converting sensor output signals into transmission signals which are transmissible through the vessel wall, and the second monitoring unit comprising means for detecting the transmission signals outside the vessel wall and deriving data representative of conditions within the vessel from the transmission signals.

The invention as defined above makes it possible to avoid penetrating a process vessel wall with any cables even in the event that for example a tomographic sensing system incorporates a large number of sensors.

Preferably, means are provided for transmitting a power signal from outside the vessel to the first monitoring unit, the first monitoring unit comprising a detector arranged to detect the power signal and a power supply energised by the detected power signal.

The first monitoring unit may comprise an antenna and an associated detector circuit tuned to a predetermined frequency, and the power signal may be transmitted at the predetermined frequency.

The vessel may incorporate a window, and the first monitoring unit may be arranged to transmit optical transmission signals through the window to the second monitoring unit. The first monitoring unit may comprise a laser to generate the optical transmission signals. The optical signals may be infra-red signals.

The transmission signals may be radio telemetry signals to which at least a part of the vessel wall is transparent.

Referring to the accompanying drawings, an embodiment of the present invention will now be described with reference to the accompanying drawings, in which:

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Figure 1 is a vertical section through a process vessel incorporating a tomographic sensing system in accordance with the present invention;

Figure 2 is a plan view of a flexible sheet supporting a single electrode which is incorporated in the process vessel of Figure 1;

Figure 3 is a plan view of part of a further sheet carrying two electrodes also incorporated in the process vessel of Figure 1; and

Figure 4 is a section on the line 4-4 of Figure 2.

Referring to Figure 1, the illustrated process vessel has a wall 1 which completely encloses a space 2 within which for example a fermentation process is to be carried out. The vessel 1 has a steel wall in which a glass window 3 is provided, such windows being commonplace in process vessels to enable a visual inspection of the vessel contents. A first monitoring unit 4 is secured to the inside surface of the window 4 and a second monitoring unit 5 is secured to the outside surface of the window 4.

The first monitoring unit 4 is connected by a multi-way cable 6 to an electrode assembly which extends around the inner surface of the process vessel. The electrode assembly is made up of a series of units three of which are shown in Figure 1, that is units 7, 8 and 9. Each of the units is in the form of a flexible sheet adhered to the inner surface of the process vessel, the units being interconnected end to end. Figure 2 is a plan view of a sheet which can be used as the unit 7 or 8 in Figure 1. Figure 3 is a plan view of a sheet which can form the unit 9 of Figure 1. Figure 4 is a section through the sheet of Figure 2 in the direction of lines 4-4 in Figure 2.

Referring to Figures 2 and 4, the illustrated unit comprises a flexible electrically insulating substrate 10 upon which a copper electrode 11 and a series of conductive tracks 12 have been printed. An insulating layer 13 covers the conductive tracks 12 but does not cover the surface of the electrode 11 which is on the far side of the substrate 10 from the vessel wall 1. Accordingly resistance measurements may be made between any one electrode and one or more of the other electrodes in the array which are spaced around the process vessel. Each of the electrodes 11 is connected by a respective pair of tracks 12 to a terminal in a terminal array 14 provided on the electrode unit 9 (Figure 3). Each of those terminals is in turn connected by the cable 6 to the first monitoring unit 4.

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Data derived from the electrodes 11 is optically coupled through the window 3 to the second monitoring device 5. The signals coupled through the window 3 may simply directly represent outputs derived from the electrodes 11, or those outputs may be processed in the first monitoring unit 4 before transmission to the second monitoring unit 5. Thus large amounts of data may be picked up by the electrode array and transmitted to the exterior of the process vessel without it being necessary for the process vessel wall to be penetrated in any way. In the event that the process vessel has to be sterilised between processing operations the electrode array is robust and can be readily cleaned.

Given that the electrodes 11 are mounted on an insulating substrate 10 which extends to a substantial distance away from the edges of the electrodes 11, electrical fields which can be generated within a process fluid within the process vessel are not shorted out to the process vessel wall at positions close to the electrodes. Thus electrical fields emanating from the electrodes 11 can extend a substantial distance into the body of the fluid contained by the vessel. Useful data can be obtained using conventional resistance tomography techniques.

Electrode arrays may be made up from a number of the individual units such as those illustrated in Figures 2 and 3 so as to make it possible to fit electrode arrays in process vessels of different sizes using essentially standard components. Individual electrode array units may be connected end to end using the end-connectors shown in Figures 2 and 3. The electrode arrays are thin and therefore can be readily shaped so as to be adhered closely to the walls of a process vessel, enabling their use in applications where the electrode arrays cannot project substantially from the internal wall of the vessel, for example when retro-fitting electrode arrays to vessels in which stirrers are provided which sweep across the inner surface of the vessel walls. It is a relatively easy matter to produce electrode assemblies with an installed thickness of less than one millimetre.

In the illustrated case, the electrodes 11 are not insulated from the process fluids. This is appropriate in the case of an electrode array used for resistance measurements. Other tomographic configurations are however possible, for example systems based on capacitance measurement. In the case of a system used for

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capacitance measurements, the electrodes 11 may or may not be covered by the insulating layer 13.

Although in the illustrated case communication between the interior and exterior of the vessel is achieved through a window 3, it will be appreciated that the cable 6 could be fed through a suitably sealed opening in the process vessel wall, thereby enabling a direct connection to be made between the electrodes and the external monitoring unit 5.

In the case illustrated in Figure 1, it is necessary to energise the first monitoring unit 4. This could be achieved using a suitable battery-energised power pack but this would require periodic replacement of the battery. In an alternative arrangement the first monitoring unit 4 may be energised using a remote link relying upon for example inducing electrical energy by transmitting a power signal from the second monitoring unit to the first, the first monitoring unit being provided with an antenna and a detector tuned to detect the power signal, and the detector providing an output to an appropriate power supply.

In the case illustrated in Figure 1, data is transferred between the first and second monitoring units using an optical link, for example relying upon a laser or other simple optical transmission and reception systems. Other non-contact telemetry options are available however, for example infra-red systems and radio telemetry links.

In the illustrated case, the sensor array is supported on the inside surface of a side wall of a vessel. It will be appreciated that the sensor array could be mounted at any appropriate position in the process vessel, including the top wall, the bottom wall or floor, or on a support surface within the vessel, for example on an impeller blade of a stirrer assembly or a support base of a filter which does not itself form part of the containment wall.

In the illustrated case, the sheet is a laminar structure with the conducting electrodes and connections deposited on an insulating substrate. Other structures are possible, for example a filter cloth in which the cloth supports the conducting electrodes and connections on a suitably insulating substrate, or the electrodes and connections are deposited directly on the cloth e.g. by painting, or the electrodes

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and/or connections are incorporated as conductive elements or threads within the cloth.

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